MgB_2 SUPERCONDUCTORS

This application claims the benefit of U.S. Provisional Application No. 60/275,067, filed on March 12, 2001.

BACKGROUND

Field of the Invention

This invention relates to superconductors and devices based on superconductors.

Discussion of the Related Art

Recently, Akitmitsu et al. discovered that a well-known compound, i.e., MgB_2, exhibits superconductivity at temperatures lower than about 39 Kelvin (K). Powders formed of MgB_2 are produced by chemically reacting magnesium (Mg) and boron (B) at a temperature in the range of about 800° Celsius to about 950 ° Celsius (C). Powders of polycrystalline MgB_2 in which individual crystalline grains of MgB_2 have diameters in the range of about 1 micron to about 50 microns are available commercially.

SUMMARY

In one aspect, the invention features a solid structure. The structure includes a substrate and a layer located on a surface of the substrate. The layer includes crystalline or polycrystalline MgB_2.

In another aspect, the invention features a process for making a thin-layer device. The process includes providing a solid body of MgB_2 and ejecting MgB_2 from the body by directing laser light onto the body. The process also includes growing a layer on a surface of a substrate from a portion of the ejected MgB_2.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a magnified view of a portion of a solid polycrystalline body formed of MgB_2;

Figure 2 is a flow chart for a process of producing the body of Figure 1;

Figure 3 shows a structure that includes a thin layer of MgB_2;

Figure 4 shows a setup for producing the thin-layer structure of Figure 3 by pulsed laser deposition (PLD);

Figure 5 is a flow chart for a process for making the structure of Figure 3;

Figure 6 shows a superconducting quantum interference device (SQUID) formed from the thin-layer structure of Figure 3; and

Figure 7 shows a helium level gauge that uses the body of Figure 1.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Though recent discoveries have shown that MgB_2 is a superconductor. The available powder form of MgB_2 is not useful for many types of superconducting devices. Furthermore, the powder form of MgB_2 is not adapted to use in many manufacturing processes. For these superconducting devices and manufacturing processes, solid bodies and thin layers of MgB_2 are more convenient. Solid bodies and thin layers of MgB_2 are provided by processes of various embodiments.

Figure 1 shows a portion of a three-dimensional solid body 10 of MgB_2 having at least one linear dimension of 1 millimeter (mm) or more. The body 10 includes a plurality of crystalline grains 12-14 and is thus, polycrystalline. The grains 12-14 have diameters in the range of about 1 micron to about 50 microns. The solid body 10 is a superconductor, at least, for temperatures below about 39 K.

Figure 2 is a flow chart for a sintering process 20 that produces a solid body of MgB_2, e.g., the polycrystalline body 10 of Figure 1. The process 20 includes compressing a quantity of MgB_2 powder with a pressure in the range of about 100 bars to about 50,000 bars (step 22). While being compressed, the quantity of powder is sintered at a temperature of about 500°C to about 900°C (step 24). In an exemplary embodiment, a pressure of about 20,000 bars and a temperature of about 700 °C are applied to the quantity of MgB_2 powder for time in the range of about 0.5 hours to about 2.0 hours. After the sintering, the process 20 includes gradually cooling the sintered MgB_2 body to room temperature (step 26). The final sintered body is a polycrystalline solid adapted for use in superconducting devices and in extreme manufacturing processes such as pulsed laser deposition.

Figure 3 shows a thin-layer structure 30 that includes a MgB_2 layer 32 and a substrate 34 on which the layer 32 is grown. The MgB_2 layer 32 is polycrystalline or crystalline and has a thickness "d" in the range of about 10 nanometers (nm) to about 1 micron. The MgB_2 layer 32 is superconducting at low temperatures, e.g., temperatures below about 39 K.

MgB_2 layer 32 and substrate 34 have similar lattice constants. In the plane of common surface 36, the lattice constants of the layer 32 and substrate 34 differ by less than 10 percent. In many embodiments, in-planar lattice constants differ by less than about 1 percent. The similarity of the in-plane lattice constants of the MgB_2 layer 32 and the substrate 34 enables the MgB_2 layer 32 to be grown in crystalline or polycrystalline form on the surface 36 of the substrate 34, because the similarity of in-plane lattice constants reduces strain energies during layer growth.

An exemplary substrate 34 is 6H-SiC (6-layer hexagonal silicon carbide), which has in-plane lattice constants of about 0.3081 nm along surface 36. These in-plane lattice constants are very similar to those of MgB_2. The lattice constants along surface 36 for the grown MgB_2 layer 32 are equal to about 0.3085 nm.

Other exemplary substrates 34 include crystalline or polycrystalline solids formed of cubic SiC, $LaAlO_3$, $SrTiO_3$, or sapphire. Since the substrate 34 is crystalline or polycrystalline and has in-plane lattice constants that closely match those of MgB_2, layer 32 is able to grow epitaxially or c-axis oriented on surface 36 of the substrate 34.

Figure 4 shows a setup 40 for producing the structure 30 of Figure 3 by pulsed laser deposition (PLD). The setup 40 includes a pulsed ultraviolet (UV) laser 41, a vacuum chamber 42, a target pellet 43, a crystalline substrate 44. An exemplary pulsed UV laser 41 has a wavelength of about 250 nm, a pulse rate of about 0.5 – 10 Hz, and an energy density on the target of about 1 - 50 Joules/cm^2. The target pellet 43 is solid body formed of polycrystalline MgB_2, e.g., a solid body made by sintering process 20 of Figure 2. The substrate 44 is an epitaxial growth base for MgB_2 such as a crystalline or polycrystalline solid of 6H-SiC, cubic SiC, $LaAlO_3$, $SrTiO_3$, or sapphire. The substrate 44 is positioned to face the surface of the target pellet 43 that is struck by an output beam 46 of the laser 41. For example, the substrate 44 may be held vertically above the target

pellet 43 at a position that intersects a plume 52 of particles that is ejected from the target pellet 43 by the action of the pulsed laser beam 46 during PLD.

Figure 5 is a flow chart showing a PLD process 60 for growing a layer 45 of MgB_2 with setup 40 of Figure 4. The process 40 includes providing a solid target pellet 43 of polycrystalline MgB_2, e.g., a pellet produced by sintering process 20 of Figure 2 (step 62). The process 40 also includes directing a pulsed output beam 46 from laser 41 onto the solid target pellet 43 (step 64). The pulsed output beam 46 ejects MgB_2 particles 48-50 to form a plume 52 over the target pellet 43. The ejected particles 48-50 typically have diameters of about 0.1 nm to about 10 nm. A portion of the ejected particles 48-50 in the plume 52 are deposited on substrate 44 (step 66). The deposition produces an epitaxial growth of layer 45 of cubic MgB_2 provided that the substrate 44 has in-plane lattice constants that approximately match those of MgB_2 along the exposed surface of the substrate 44. For example, a mismatch of in-plane lattice constants by 1 percent still enables layer 45 to grow in a crystalline or polycrystalline form.

To improve the deposition of MgB_2, the substrate 44 and pellet 43 are positioned in a vacuum chamber 42, which maintains internal pressures in the range of about 10^{-8} Torr to about 10^{-4} Torr. Pressures in this range reduce oxidation of the MgB_2, which could produce MgO. The presence of MgO could otherwise interfere with the deposition of MgB_2. However, the inclusion of a small amount of MgO into the MgB_2 layer could enhance certain superconducting properties such as the value of the critical current.

Figure 5 is an oblique view of a superconducting quantum interference device (SQUID) 70. The SQUID 70 is formed by etching thin-layer structure 30 of Figure 3, e.g., by a lithographic process, to remove the MgB_2 from both central region 72 and tunneling junction regions 74, 76. After the etch, the structure includes a ring 78 of MgB_2 whose current properties can be used to measure the value of the magnetic flux through the central region 72.

Figure 6 shows a liquid helium (He) gauge 80 that measures the height of the surface 82 of the He liquid 83 in dewar 84. The gauge includes an elongated body 86 of solid MgB_2, which is formed by sintering process 20 of Figure 2. The body 86 includes a cooler portion 88, i.e., located in the He liquid 83, and a warmer portion 90, i.e., located above the He liquid 83. The cooler portion 88 is superconducting, and the warmer

portion 90 is not superconducting. The gauge 80 determines the level of the surface 82 from the reading from an ohmmeter 92. Changes in the reading are proportional to level changes of the liquid He, because the resistance of the body 86 of solid MgB_2 is proportional to the length of the body 86 that is not in the He liquid 83, i.e., the length that is cooled to a superconducting state.

From the disclosure, drawings, and claims, other embodiments of the invention will be apparent to those skilled in the art.